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Comparison of breast motion at different levels of support during physical activity

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ABSTRACT

Optical tracking systems have been used in previous studies to capture the motion of the nude breast and breasts in bras, under the assumption that no breast-bra relative movement occurred within the bra. This study compared breast and bra movement through electromagnetic tracking and optical tracking systems to determine the relative breast movement occurring with different breast support and exercise-induced breast discomfort. Total of 30 female participants (mean age: 21.5 ± 2.3 years; cup sizes: A-F) were recruited and their movement at four different levels of breast support was recorded in two motion capture systems for further analysis and comparison. Significant differences between bra and breast vertical displacement were found at all support levels during periods of intense movement ($r = 0.556$; $p < 0.05$). Because the greatest bra displacement was observed when participants wore an everyday bra and the greatest breast displacement was observed when participants wore a crop-top bra, there was evident inconsistency in bra and breast motion and a high-impact sports bra was the most effective to reduce breast movement and discomfort among the four types of bras. An electromagnetic tracking system provided direct observation of the actual movement of the breasts, and an optical tracking system enabled us to monitor bra displacement. Significant differences were observed in bra and breast displacement during the intense movements included in this study. The results bring into question the assumption made in previous studies that no relative movement occurs within a breast support garment. **Key words:** DISPLACEMENT, EVERYDAY BRA, SPORTS BRA, CROP-TOP BRA.

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INTRODUCTION

An ill-fitting bra can cause back and neck pain, upper limb neural symptoms (which engender paresthesia and fatigue), breast pain, and deep bra furrows resulting from excessive strap pressure (De Silva, 1986; Kaye, 1972; Ryan, 2000). These symptoms can sometimes be so severe that women are forced to seek reduction mammoplasty (Ryan, 2000; Greenbaum *et al.*, 2003) or prevented from participating in physical activity. However, when a well-designed and well-fitted sports bra is worn, exercise-induced discomfort caused by excessive breast displacement can be greatly reduced (Hadi, 2000; McGhee & Steele, 2010; Scurr *et al.*, 2010; White *et al.*, 2011; Wilson & Sellwood, 1976; Zhou & Yu, 2012) and women are able to enjoy physical activity again. Although several studies have promoted and encouraged the wearing of sports bra during physical activity, a considerable number of women in Taiwan are unaware of this information, and often wear their daily bra rather than an appropriate sports bra during exercise. This study focuses on the impact of three types of bra (crop-top, everyday bra, and sports bra). Previous research analyzing bra-breast motion has adopted optical tracking systems to capture the motion of the nude breast and breasts supported by sports bras (Scurr *et al.*, 2009, 2010; White *et al.*, 2009, 2011; Mason *et al.*, 1999; Zhou *et al.*, 2012). These motion data were collected and further analyzed under the assumption that no breast-bra relative movement occurred within the bra. However, the relative movement within nonsports bras cannot be neglected, because they usually provide lighter support than sports bras, and this is attributable to differences in materials and structure. McGhee et al. (2013) introduced an infrared emitting diode, rather than the passive retroreflective markers used in previous studies, to detect breast motion within the bra, but they did not include a comparison of the relative movement of the bra and the breasts. The reflective markers of an optical tracking system require excessive space to appropriately measure the actual movement of breasts within a bra; the tiny, paper-thin sensors of an electromagnetic tracking system are a more favorable choice.

Research on breast motion has often involved large-breasted women, classified by Lorentzen and Lawson (1987) as women with a cup size above D. Large breasts have greater mass at the chest anterior to the thoracic cage and more drastic displacement in all directions compared with smaller ones. This renders it understandable that D-cup subjects have been selected as the focus of many studies (White *et al.*, 2009, 2011; McGhee *et al.*, 2013; Scurr *et al.*, 2011). Vertical displacement has been confirmed to be greatest during running and jogging (Mason et al., 1999; Scurr *et al.*, 2009; White *et al.*, 2009) , and Zhou et al. (2012) showed that pert and ptotic breasts move in different patterns, with more anterior and medial movement occurring in the ptotic breasts. With insufficient support, large-breasted women tend to experience ptosis, and consequently, the larger breast movement contributes to breast pain. McGhee et al. (2013) investigated the correlation between bra-breast force and breast pain during exercise. The difference in the vertical displacement between high and low-level breast support was greater in large-breasted participants, indicating that a large breast mass required different bra design to prevent considerable breast movement (McGhee *et al.*, 2013). Although the study by McGhee et al. (2013) focused on the bra-breast force generated in the bra during exercise, White (2013) recruited eleven female recreational runners (age: 26 ± 7 years) whose cup size ranges D to E (larger-breasted) and discovered that exercise performance at different levels of breast support varied with participant comfort. A shorter mean stride length and decreased knee flexion angle were observed at decreased levels of breast support during treadmill running. The changes in performance were intended to render exercise more comfortable; specifically, women with insufficient breast support may feel such excessive breast discomfort.

This study specifically investigates the effect of different levels of breast support on breast movement and exercise-induced discomfort and provides a scientific basis for proper bra selection. We hypothesized that, relative displacement between the breasts and bra, as indicated by sensors from an electromagnetic tracking system and markers from an optical tracking system, respectively, occurs at all levels of breast support.

MATERIAL AND METHODS

Participants

This study involved a total of 30 young, active female volunteers (mean age: 21.5 ± 2.3 years; cup sizes: A-F) who had no experience of breast surgery, pregnancy, giving birth, or breast feeding within the previous year. All participants were informed of the content of the procedures and protocols before the start of the experiments and signed an informed consent form describing the possible risks and benefits. The study protocol was approved by the Human Experiment and Ethics Committee of National Cheng Kung University Medical Center, Tainan, Taiwan (B-ER-103-055).

Experimental procedures

Based on research by Haake and Scurr (2010), to collect kinematic data of bra, five retroreflective markers (1.9 mm) from a digital optical tracking system (100 Hz) were attached to the suprasternal notch, the left and right nipples (hereby referring to the corresponding positions of nipples on the bra), and the left and right anterior inferior aspect of the 10th ribs (Figure 1) (Haake & Scurr, 2010). These markers allowed for the collection of bra displacement data.

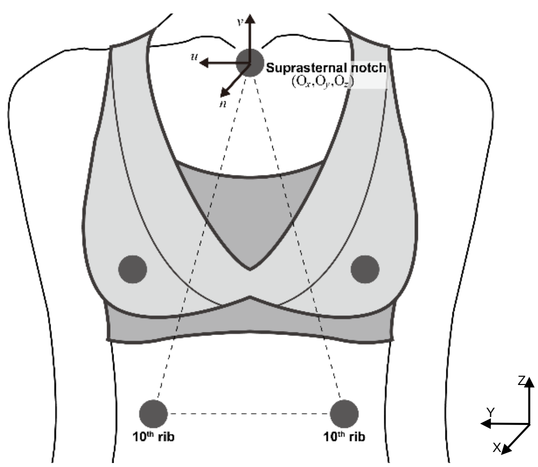

Figure 1. Marker set used to measure the motion of the bra and breast; the origin of the local coordinate system (O_x, O_y, O_z) was set at the suprasternal notch.

Five passive sensors (0.9 mm) from an electromagnetic tracking system were attached directly beneath the retroreflective markers. Two of the passive sensors were attached to the nipples directly rather than to the corresponding positions on a bra. Through these sensors, the actual movement of the breast could be observed. Five calibrated ProReflex infrared cameras (Qualisys, Sweden) were placed in front of the participants in a hemisphere arrangement. A 3D Guidance trakSTAR™ (Ascension Technology Corp., USA) short-rang transmitter connected to the electronic units of the electromagnetic tracking system was placed behind the participants.

The participants were requested to perform lateral raises and chest expansion in an upright standing position, vertical jumps, and lateral raises and chest expansion during low-impact step aerobics while wearing a crop top, an everyday bra, a light-impact sports bra, or a high-impact sports bra (Table 1) (White *et al.*, 2011; Mason *et al.*, 1999). The participant performed the lateral raise by raising the arms out to the sides until they're at shoulder level, pause, then return to the starting position. The chest expansion involved forward elevated arms moving toward lateral sides with expanded chest. These two motions involved chest movement followed by breast movement.

Table 1. Information about the bras (crop-top bra, light, and high sports bra) utilized in the study.

Breast support	Crop-top bra	Light sports bra	High sports bra
Illustration (front view)			
(back view)			
Textile	Nylon ·········· 95% Spandex ·········· 5%	Nylon ·········· 51% Spandex ·········· 11% Polyester ·········· 38%	Nylon ·········· 95% Lycra ·········· 5%
Characteristics	◆ Removable pads	◆ Racer back ◆ Slim adjustable strap ◆ Compressive cups with removable pads	◆ Racer back ◆ Adjustable closure ◆ Compressive cups with pads
Application	casual, daily wear	low-intensity activities	medium-/high-intensity activities

The participants completed a 2-s static recording in an anatomical reference position prior to the performance of the required movements to establish the laboratory coordinate system. A visual analog scale for breast comfort (White et al., 2011; Mason et al., 1999) was rated immediately after every set of movements (0 = comfortable, 5 = uncomfortable, 10 = painful). The first set of movements involved only upper-limb movements, and the second set included a selected series of low-impact step aerobics.

Markers were identified and 3D data were reconstructed using Qualisys Track Manager (QTM) Software. To establish breast motion independent of the trunk motion, a transformation matrix (Hughes *et al.*, 2013) was used to convert the absolute motion in the laboratory coordinate system (LCS) to the relative coordinate system (BCS). The suprasternal notch was the origin of the LCS; the reference vector u (Figure 1), created by the two markers on the 10th ribs, determined the upper body pitch. The three markers above composed the upper body reference plane for the LCS. Vector n was perpendicular to the reference plane, whereas reference vector v was vertical (Haake & Scurr, 2010). The 3D outcome data after reconstruction in QTM were imported into Matlab (MathWorks Inc.) for further comparative analysis with the data from the electromagnetic tracking system. The data collected in the electromagnetic tracking system were immediately transmitted to the computer and a simple metrical calculation was performed for comparable outcomes with the processed data sourced from the digital tracking system. The 3D trajectories of the reflective markers and passive sensors were smoothed using a 10-Hz low-pass Butterworth filter (Haake & Scurr, 2010).

Statistical analyses

A two-sample t test was used to verify whether the mean vertical displacement of the bra and breasts under each support condition in each type of movement were equal. Data were assessed for normality and homogeneity of variance. A p-value < 0.05 implied a significant difference between the variables. Linear regression was used to assess the contribution of each independent variable to vertical displacement at each movement. In this analysis, the dependent variable was the vertical displacement, and the independent variables were the five movements and four bra types. The independent variable exhibited a significant moderate correlation ($r \geq 0.3$ and $p \leq 0.05$) with the displacement.

RESULTS

No significant difference was found in the medial and lateral displacement of either the bra or breasts.

The results showed no significant difference in the stationary lateral raises in any type of bra. During chest expansion (stationary), a significant difference in bra and breast displacement was determined only under the everyday bra (p = 0.02, Table 2). A significant difference in the vertical breast displacement and the vertical bra displacement in the vertical jumps and in lateral raises and chest expansion in low-impact step aerobics was observed in all types of bra (p < 0.05, Table 2).

The supportive effect of the light-impact sports bra or the high-impact sports bra was clearly observed in all types of movement, and was greater than that of the crop-top and everyday bras. Bland–Altman plots assessing the vertical displacement of bra and breast under each support condition in each movement (r = 0.556; p < 0.05) demonstrated absolute agreement in vertical displacement between bra and breast with 95% limits of agreement (16.48-24.11 mm) (Bland & Altman, 1986) (Figure 2).

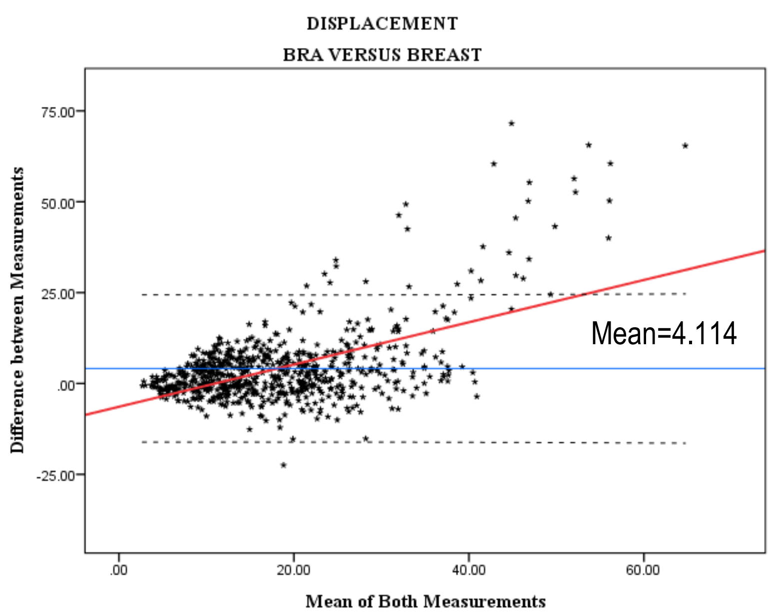

Figure 2. Bland–Altman plots assessing the vertical displacement of bra and breast under each support condition in each movement. The so lid line represents the mean difference.

Table 2. The vertical displacement of bra and breast under each support condition in each movement (mm).

Movement		Crop-top bra	Everyday bra	Light sports bra	High sports bra
Lateral raise	Bra	22.43±5.50	22.94±7.54	19.53±4.63	17.82±4.86
	Breast	20.97±6.44	20.45±6.46	18.52±4.82	17.94±5.12
	p-value	0.29	0.13	0.35	0.92
Chest expansion	Bra	17.94±5.12	11.36±4.51	7.11±2.29	7.47±3.00
	Breast	7.60±2.66	9.00±3.91	7.01±2.50	6.73±2.61
	p-value	0.27	0.02**	0.86	0.25
Vertical Jump	Bra	12.71 ±4.71	13.26 ±5.55	12.95 ±5.18	10.16 ±4.55
	Breast	18.14 ±5.43	17.56 ±6.28	18.66 ±6.40	15.08 ±4.34
	p-value	0.00***	0.00**	0.00***	0.00***
Lateral raise during step	Bra	26.63 ±6.15	27.97 ±6.74	23.45 ±5.81	20.88 ±4.06
	Breast	36.36 ±14.71	36.23 ±16.15	34.30 ±13.62	30.30 ±13.47
	p-value	0.00***	0.01**	0.00***	0.00***
Chest expansion during step	Effect size (*d*)	13.42 ±5.88	15.11 ±6.18	12.81 ±7.18	10.40 ±4.68
	Breast	23.74 ±21.00	22.39 ±15.97	21.51 ±15.08	18.27 ±15.94
	p-value	0.01**	0.01**	0.00**	0.01**

*Data = Mean ± Standard deviation; * p< 0.05, ** p < 0.01, *** p < 0.001*

DISCUSSION

This study compared the movement of the breasts and bra through electromagnetic tracking and optical tracking systems to determine the relative breast movement occurring within the bra and exercise-induced discomfort.

Because of the specific movement required in this study, no significant difference was found in the medial and lateral displacement of either the bra or breasts. The association between vertical breast displacement and exercise-induced breast discomfort in physical activity has been demonstrated in previous studies (Mason *et al.*, 1999; McGhee *et al.*, 2013; Lorentzen & Lawson, 1987; Starr *et al.*, 2005). The everyday bras in this study were those worn daily by the participants. The cup materials were mostly lace or cotton, and the design was either padded or nonpadded, providing a wide variety of styles. On the basis of this bra design, the vertical displacement between the low-support everyday bra and the breasts during chest expansion in an upright standing position was expected to be particularly significant (p = 0.02). The everyday bra was designed for daily routines rather than physical activities; thinner shoulder straps and bra bands and flimsier material in each part could all contribute to greater bra displacement (11.36 ± 4.51 mm) than breast displacement (9.00 ± 3.91 mm). As our study shows, everyday bras trigger exercise-induced breast discomfort and cause greater vertical bra movement during chest expansion. The lower level of coverage and support renders the everyday bra less protective, a finding that women should take into consideration when participating in physical activity.

As defined by Sports Medicine Australia, a crop-top bra is one “without cups compressing the breast to the chest.” Although the greatest bra displacement was found in an everyday bra, the greatest breast displacement was determined in a crop-top bra during most types of movement (Table 1) The material of the crop-top bra, compared with a sports bra with equal amounts of nylon, is rather loose and flexible. The design of the crop-top bra did not include underwires or other features to secure the breasts to the chest. When these factors are taken into consideration, our findings of greater breast displacement are expected.

The vertical motion of the unsupported breasts increased by 70% and 30% as greater forces were generated during running and walking, respectively, in proportion to increased breast mass (Haake & Scurr, 2010; Tumer & Dujon, 2005). When breast mass increased from 120 to 690 g, the vertical displacement of the bare breasts increased by nearly 100% (0.0435 to 0.0856 m) during treadmill running (Wood, et al., 2012). Female athletes with larger breast sizes (beginning at a 34 DD cup) bear approximately 1150 g on the thoracic segment (Tumer & Dujon, 2005). Participants with the same cup size (D) demonstrated displacement of up to 48% during bare-breasted running (Scurr *et al.*, 2011), and vertical breast displacement ranged from 6.68 to 9.28 cm in this group of participants; substantial displacement was also observed in smaller breast cup sizes (Lorentzen & Lawson, 1987). Sports bras are dedicated to minimizing breast displacement and maximizing protection during exercise, regardless of cup size. Theoretically, the higher the level of breast support is, the lower the level of breast displacement is; however, the bra displacement of a light-impact sports bra (7.11 ± 2.29 mm) during chest expansion was found to be much smaller than that of a high sports bra (7.47 ± 3.00 mm) and the greatest during the vertical jump. The light-impact sports bra employed in this study was constructed with thin shoulder straps and minimal coverage on the center and sides of the chest. The breast displacement in a light sports bra (18.66 ± 6.40 mm) was the greatest of the four, and the lack of coverage and compression on the upper part of the breast might be responsible for that.

Women reported less vertical breast displacement and exercise-induced breast discomfort when wearing high-impact sports bras than when wearing everyday bras (McGhee *et al.*, 2013; Lorentzen & Lawson, 1987; Starr *et al.*, 2005). The four bra types in this study showed significant differences in the vertical displacement of the bra and breast during the vertical jump and low-impact step aerobics ($p < 0.05$). The high-impact sports bras (10.16 ± 4.55 mm) limited breast vertical displacement (15.08 ± 4.34 mm) ($p < 0.00$) during the vertical jump and low-impact step aerobics. The downward phase of the breast cycle referred to the duration when the breast moved below the static equilibrium level; according to McGhee et al. (2013), the mean peak instantaneous vertical breast acceleration and the peak bare-breast forces occurred during this phase. Sports bra design and fabrics vary depending on the different physical activities for which they are intended. Therefore, differences in vertical displacement may be observed between the current study and previous research.

Sports bras are now widely recommended by experts and specialists as protective equipment that provides firm support to the breasts during physical activity. Nevertheless, women in Taiwan are not commonly aware of the importance of appropriate sportswear and rarely change before engaging in physical activity. This renders examining the extent of the different levels of breast support and displacement highly crucial. During all types of movement, with the exception of lateral raises, the everyday bra demonstrated a significant difference between bra and breast displacement, suggesting insufficient support.

Some limitations of our study should be considered. We identified breast displacement during vertical jumps, and lateral raises and chest expansion in low-impact step aerobics based on previous researches (White *et al.*, 2011; Mason *et al.*, 1999). Difference in movement between daily activities and low-impact step aerobics can't be ignored, so further study is needed for general application of this result. Bra choice varies from country to country and person to person. The bras chosen in this study are very common among female Taiwanese, whom are participants in this study.

CONCLUSION

Significant differences were observed in different levels of breast support and displacement during the low-intensity movements included in this study. The results bring into question the assumption made in previous studies that no relative movement occurred within the bra set. Breast displacement was found to be greatest in a crop-top bra, and an everyday bra demonstrated the greatest bra displacement. A high-impact sports bra was the most effective of four bra types to reduce breast movement and discomfort.

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